SKYNET 5
SpaceWx in Operational Practice

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SKYNET Spacecraft Management Authority

SMA 700 – 170427

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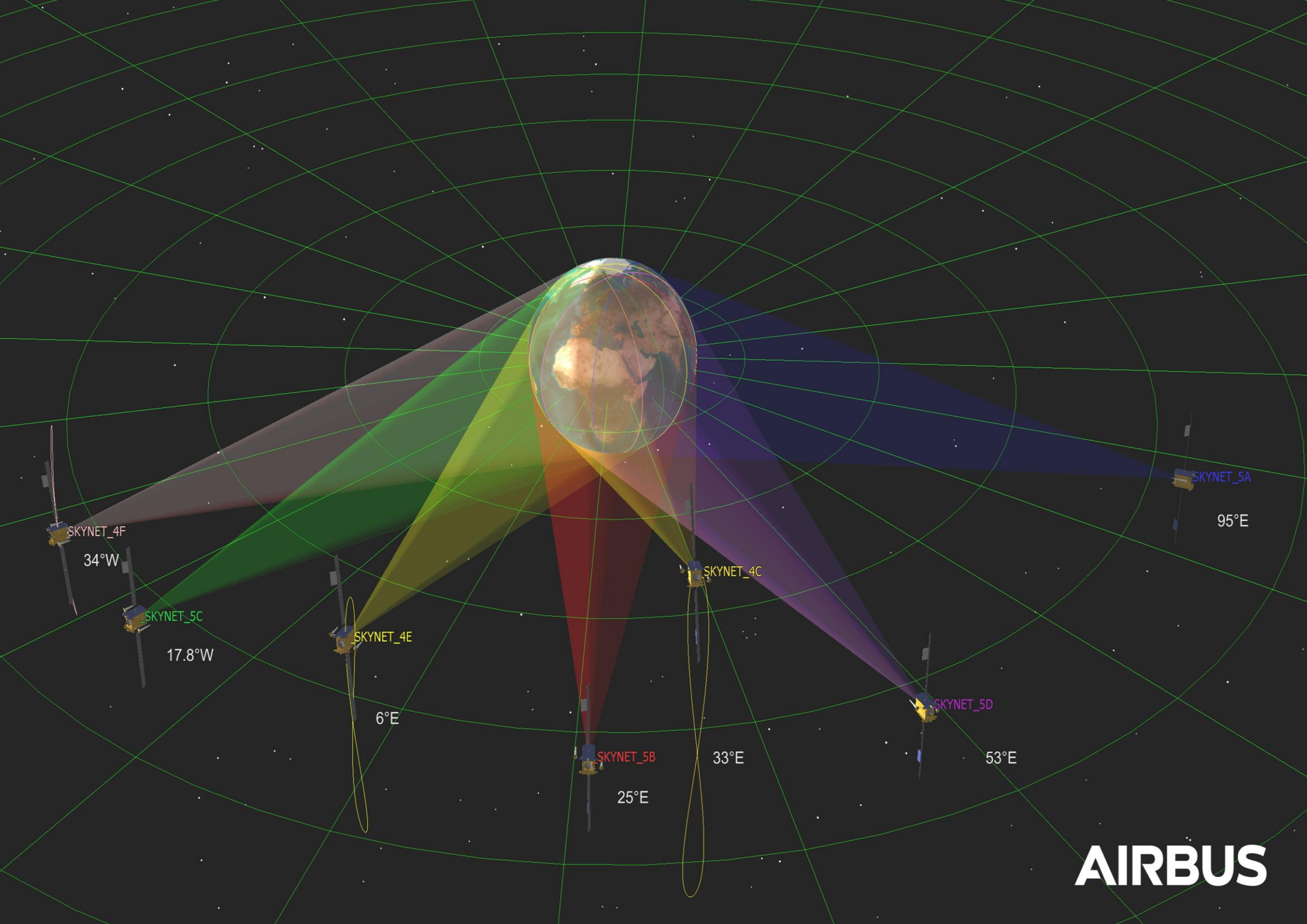
SKYNET_4F
34°W
SKYNET_5C
17.8°W
SKYNET_4E
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SKYNET_5B
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SKYNET_4C
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SKYNET_5D
53°E
SKYNET_5A
95°E
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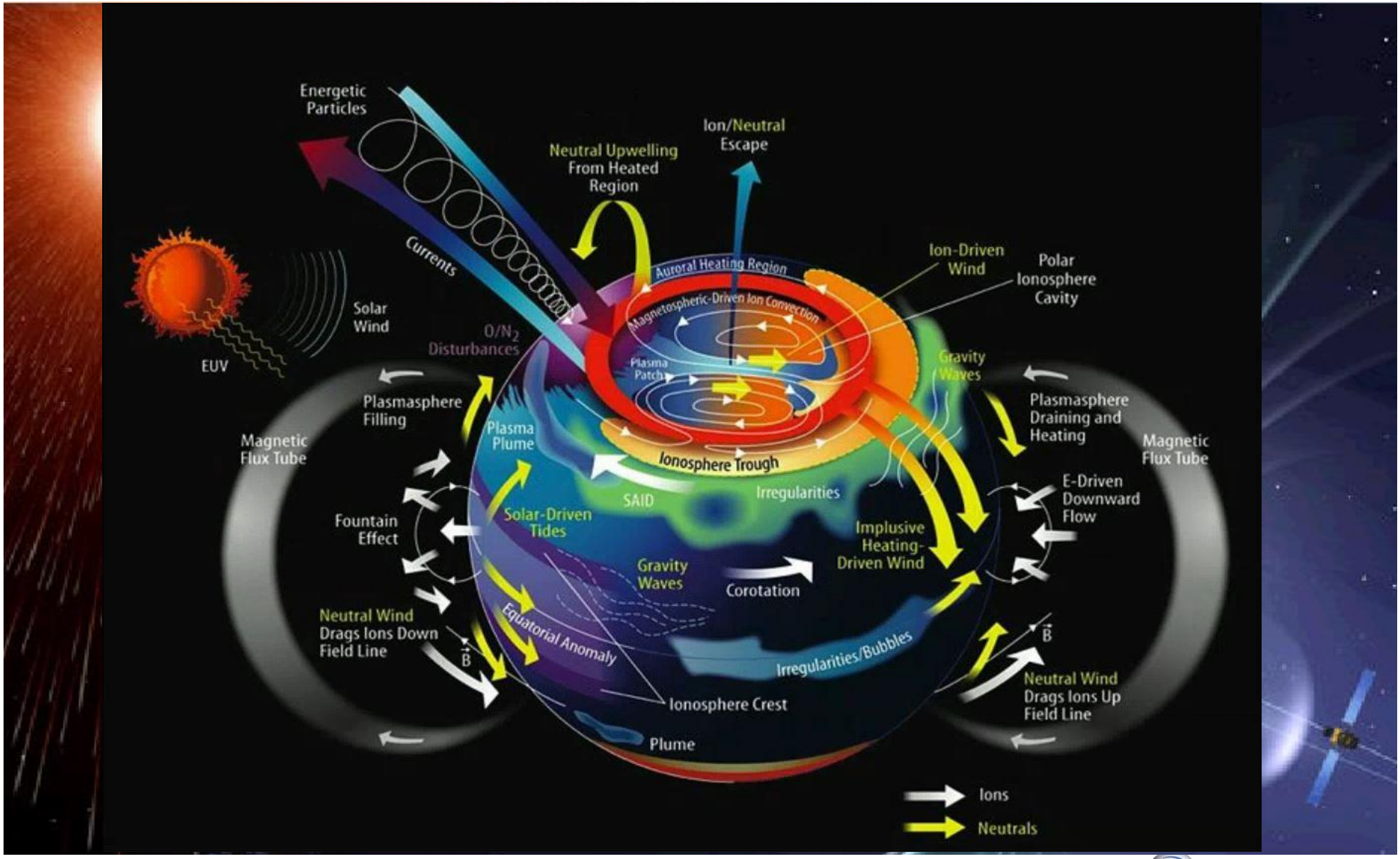
MAY 2013: A SUN ODYSSEY

synestethic interpretation of solar activity

The Complexity of SpaceWx is Difficult to Envisage Operationally



Planning and Mitigating Space Operations

SpaceWx has the potential to impact Space Operations very broadly through many mechanisms and interactions.

Space-Based Services Provision

- Scintillation of the Ionosphere impeding uplink and downlink
- Degradation of GNSS providing both Navigation and Timing

Controlling, Managing and Maintaining Spacecraft

- Interruption to Telemetry, Tracking and Control signals
- Spacecraft materials damage over time
- Onboard memory corruptions and spurious switching

These may give rise to ‘anomalies’

Function and Availability of the Ground Segment

- Interruption of Power
- Terrestrial Data lines to Satellite Ground Stations
- Personnel movement due to impact on transportation

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A Space Services Provider's Perspective on Space Services Users

Space Systems to the Space Service Users 'Just work' (… and that's a good thing!)

High reliability is built-in to Space Systems design at all levels, providing functional Diversity and Redundancy.

BUT – Severe SpaceWx impacts Space Services in ways Space Systems may only mitigate in a limited way.

- Which of your Service Delivery components rely directly or indirectly on a Space System?
- Do any of your backup Service Delivery components have which have themselves Space Systems dependencies?

GNSS – Earth Observation – Communications – Data Transfer …

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A Typical SpaceWx Forecast - 170418

Met Office Space Weather Operations Centre (MOSWOC)

Space Weather Impact on SATCOM Assessment

Issued: 18 April 2017

18 April 2017	0001 Z to 0600 Z			0600 Z to 1200 Z			1200 Z to 1800 Z			1800 Z to 2400 Z		
	VHF	UHF	SHF	VHF	UHF	SHF	VHF	UHF	SHF	VHF	UHF	SHF
High Latitude	F	F	F	F	F	F	F	F	F	F	F	F
Mid latitude	F	F	F	F	F	F	F	F	F	F	F	F
Equatorial	F	F	F	F	F	F	F	F	F	F	F	F

Comments: Nil.

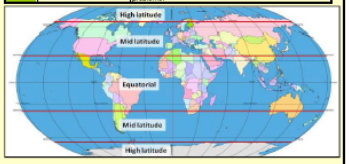
19 April 2017	0001 Z to 1200 Z			1200 Z to 2400 Z		
	VHF	UHF	SHF	VHF	UHF	SHF
High Latitude	F	F	F	F	F	F
Mid latitude	F	F	F	F	F	F
Equatorial	F	F	F	F	F	F

Comments: Nil.

20 April 2017	0001 Z to 1200 Z			1200 Z to 2400 Z		
	VHF	UHF	SHF	VHF	UHF	SHF
High Latitude	F	F	F	F	F	F
Mid latitude	F	F	F	F	F	F
Equatorial	F	F	F	F	F	F

Comments: Nil.

U	Unfavourable	Frequent or general signal loss, signal fade and/or interference are likely.
M	Moderate impacts	Occasional or intermittent periods of signal loss, signal fade and/or interference are likely.
S	Slight degradation	Isolated or periods of slight signal loss, signal fade and/or interference are likely.
F	Favourable	The environment is unlikely to contribute to communications problems.



This forecast provides guidance on anticipated communications effectiveness for the stated geographic area and period.

For further space weather advice contact UK SpOC Tel: 01494 494068/95221 X4068
This product is issued daily from MOSWOC and is non amendable.

Feedback on this product would be welcomed and should be directed to UK SpOC at Air-1GP-BMSpaceOpsCCGroup@mod.gov.uk

Geomagnetic Storms:

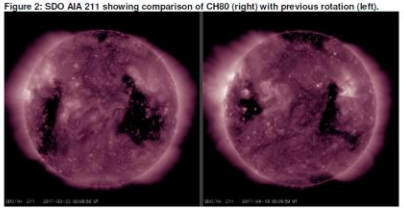
On days 1 to 3 (18-20 Apr) solar winds are likely to increase in response to a connection to positive coronal hole 80, with a likelihood of Active (Kp4) periods, and a chance (20%) of isolated minor storms (G1). There is some uncertainty with this coronal hole as its leading section is markedly smaller and less well defined than on the previous rotation. The better defined western section of the coronal hole is likely to connect on day 2 or 3, with solar wind speeds starting to decrease by day 4. As this is a positive coronal hole and we are nearing spring equinox, impacts are likely to be limited.

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	10	30	30	20
Strong	G3	No	1	1	1	1
Severe	G4	No	1	1	1	1
Extreme	G5	No	1	1	1	1

Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure 2: SDO AIA 211 showing comparison of CH80 (right) with previous rotation (left).



Radio Blackouts - X Ray Flares:

There is a chance of R1-R2 radio blackouts through the period as a result of a returning active region (ex-AR2644) which gave a number of M-class flares on it's previous rotation. A full analysis is not yet possible due to the position of the region on the eastern limb and probabilities will be revised accordingly as it moves further into view. Evidence from Stereo A EUV suggests it is still a large, complex region. Background X-Ray flux levels have increased in response and a C2.0 flare was observed from this region at 17/0245 UTC from around the limb, along with a number of b-class flares.

X Ray Flares Probability	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	No	10	20	20	20
Very Active	R3 to R5 X Class	No	1	2	2	2

Solar Radiation Storms - (High Energy Protons):

The flux of high energy protons (greater than 10 MeV) is forecast to remain at background levels. Although there is a chance of significant flare activity from returning region ex-2644, this will be in an unfavourable position on the eastern side of the disc over the next 4 days.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	S1	No	1	1	1	1
Very Active	S3 *	No	1	1	1	1

* S3 10 MeV 1000 pfu and / or 50 MeV 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)

Space Weather Technical Forecast

Issued on Tuesday, 18 April 2017 at 01:30 local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales http://www.metoffice.gov.uk/services/public-sector/emergencies/space-weather/uk-scales

Space Weather Forecast Headline: Chance of G1 geomagnetic storms and R1-R2 radio blackouts during the forecast period.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Solar activity has been low over the past 24 hours. A number of b-class flares and a C2.0 flare (observed 17/0245 UTC) originated from returning region ex-AR2644 which is currently transiting around the eastern limb. A weak coronal mass ejection from this area may have been associated with the C2.0 flare, although is not Earth-bound. There are no other active regions on the visible disc with no Earth directed coronal mass ejections observed.

Solar Wind / Geomagnetic Activity: The solar wind measured at L1 (DSCOVR) has been at background levels, close to 300 km/s. Density decreased from 11 parts per cc initially to between 3 and 5 parts per cc from 17/0400 UTC. The total magnetic field (Bt) was between 3 and 5 nT. The Bz component varied between minus 4 and plus 4 nT. The Phi angle started the period in the negative sector, transitioning to positive from 17/0500 UTC. Geomagnetic activity has been Quiet (Kp=0-2).

Energetic Particles / Solar Radiation: The high energy proton flux (greater than 10 MeV) remained at background levels. The high energy electron flux (greater than 2 MeV) at geosynchronous orbit reached high levels between 17/1210 and 17/2055 UTC with a peak of 1700 pfu. The 24 hour electron fluence has remained below the active threshold.

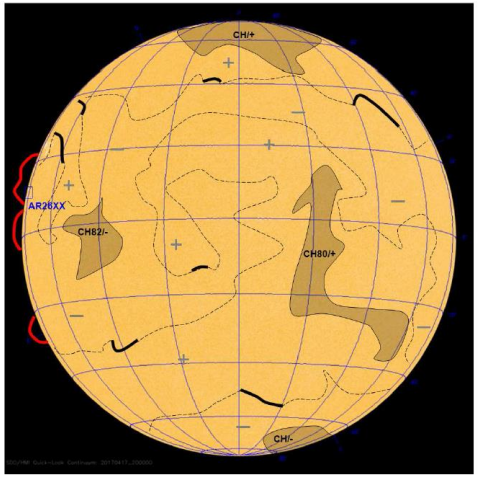
Four-Day Space Weather Forecast Summary

Solar Activity: There is chance (20%) of R1-R2 radio blackouts through the forecast period as a returning active region (ex-2644) transits onto the visible disc, having given significant flare activity on its previous rotation.

Geomagnetic Activity: From day 1 (18 Apr) solar winds are likely to increase in response to a connection to positive coronal hole 80, with a likelihood of Active (Kp4) periods and a chance (20%) of isolated minor storms (G1) on days 1 to 3.

Energetic Particles / Solar Radiation: The flux of high energy protons (greater than 10 MeV) is forecast to remain at background levels. The high energy electron flux is likely to peak at high levels during the diurnal cycle through the period, with an increasing trend. There is an increasing chance (20% on day 1 rising to 50% by day 4) of the electron fluence rising above the active threshold through the period.

Figure 1. Solar Analysis Valid 17/2000 UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

Space Weather Conditions	Day 1	Day 2-4
Local Resilience	GREEN	GREEN
Energy	GREEN	GREEN
Aviation	GREEN	GREEN
Marine	GREEN	GREEN
Satellite Operators	GREEN	GREEN
Satellite Comms	GREEN	GREEN
Rail	GREEN	GREEN

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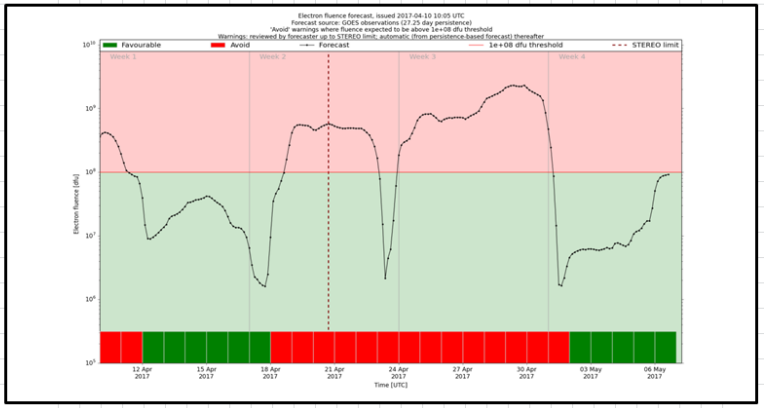
SpaceWx in Routine Spacecraft Operations

We receive SpaceWx forecasting material from the MOSWOC in several forms:

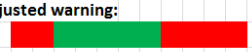
- 'Technical' and 'Natural Language' Forecasts by email twice daily.
- Configurable alerts and warnings on specific thresholds by email.
- Access to the MOSWOC website, where Sector Forecasts are updated every minute.

For specific operations, the MOSWOC has assisted us with detailed forecasts:

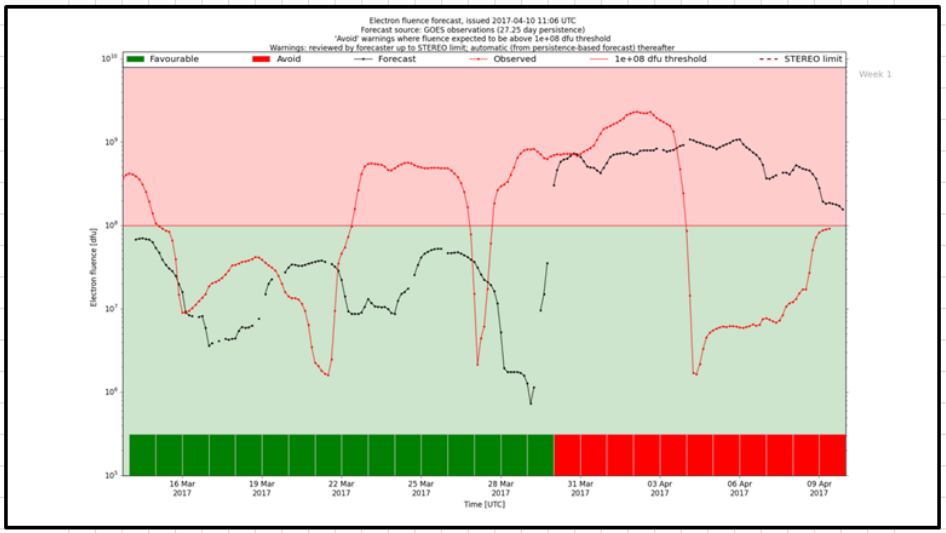
27 day electron fluence forecast. Issued 2017 Apr 10



Forecaster-adjusted warning:

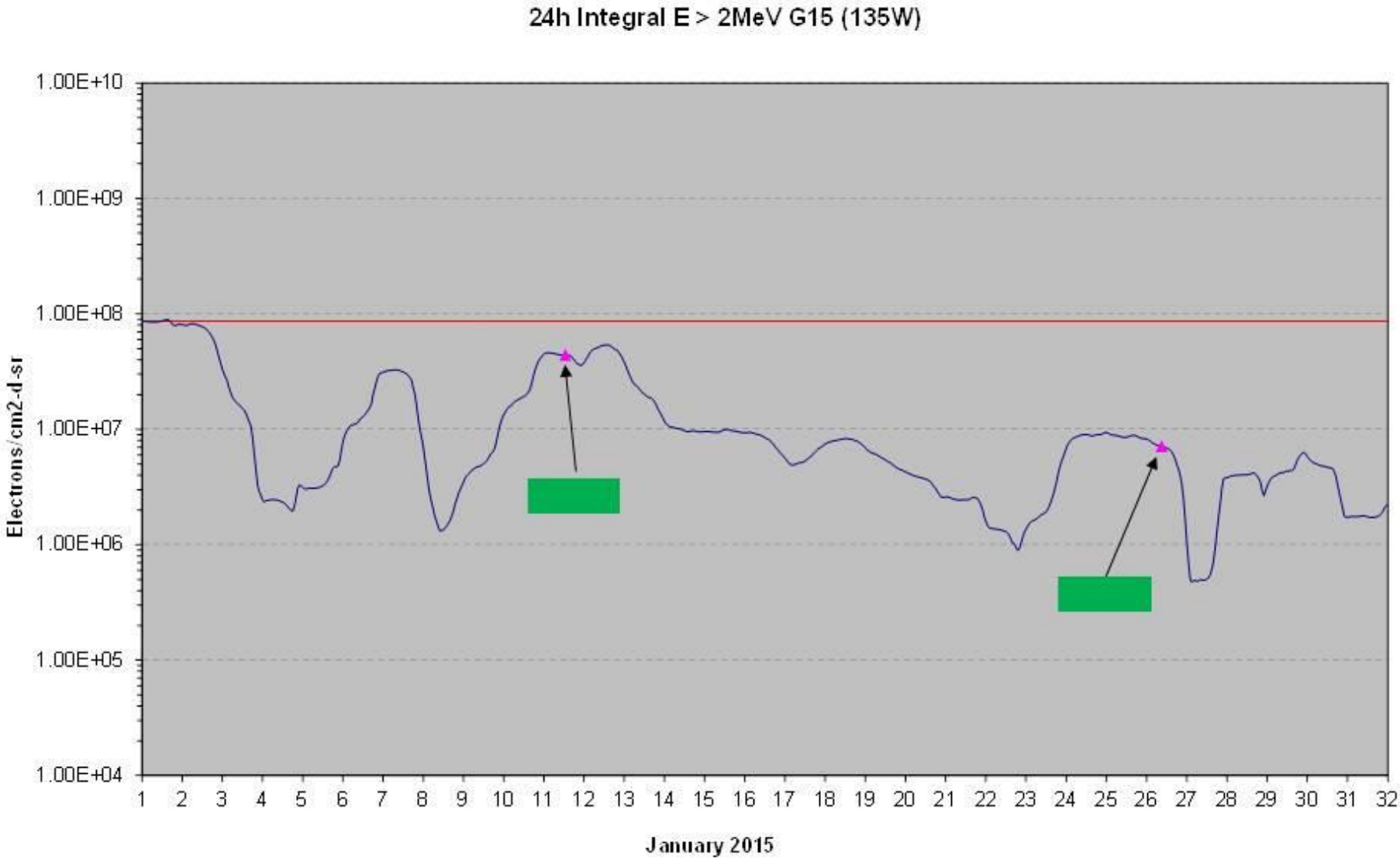


Forecaster commentary:
Week 1: Fluence levels are currently remaining fairly steady just below the 1e8 threshold but may just breach it later today or tomorrow before declining again. Conditions are then expected to be favourable for the remainder of the week although initial analysis of a CME observed leaving the sun last night suggests that a glacing blow is possible, probably around the 14th, with effects lasting for 24-48hrs. This means that confidence is currently Low.
Week 2: Conditions are expected to remain favourable until the 17th when, based on persistence, a recurrent, negative polarity HSS is expected to become geoeffective.
Week 3: Conditions are expected to be unfavourable as a result negative HSS influence.
Week 4: Favourable conditions are expected once Earth exits the negative HSS influence on the 2nd May (based on persistence).

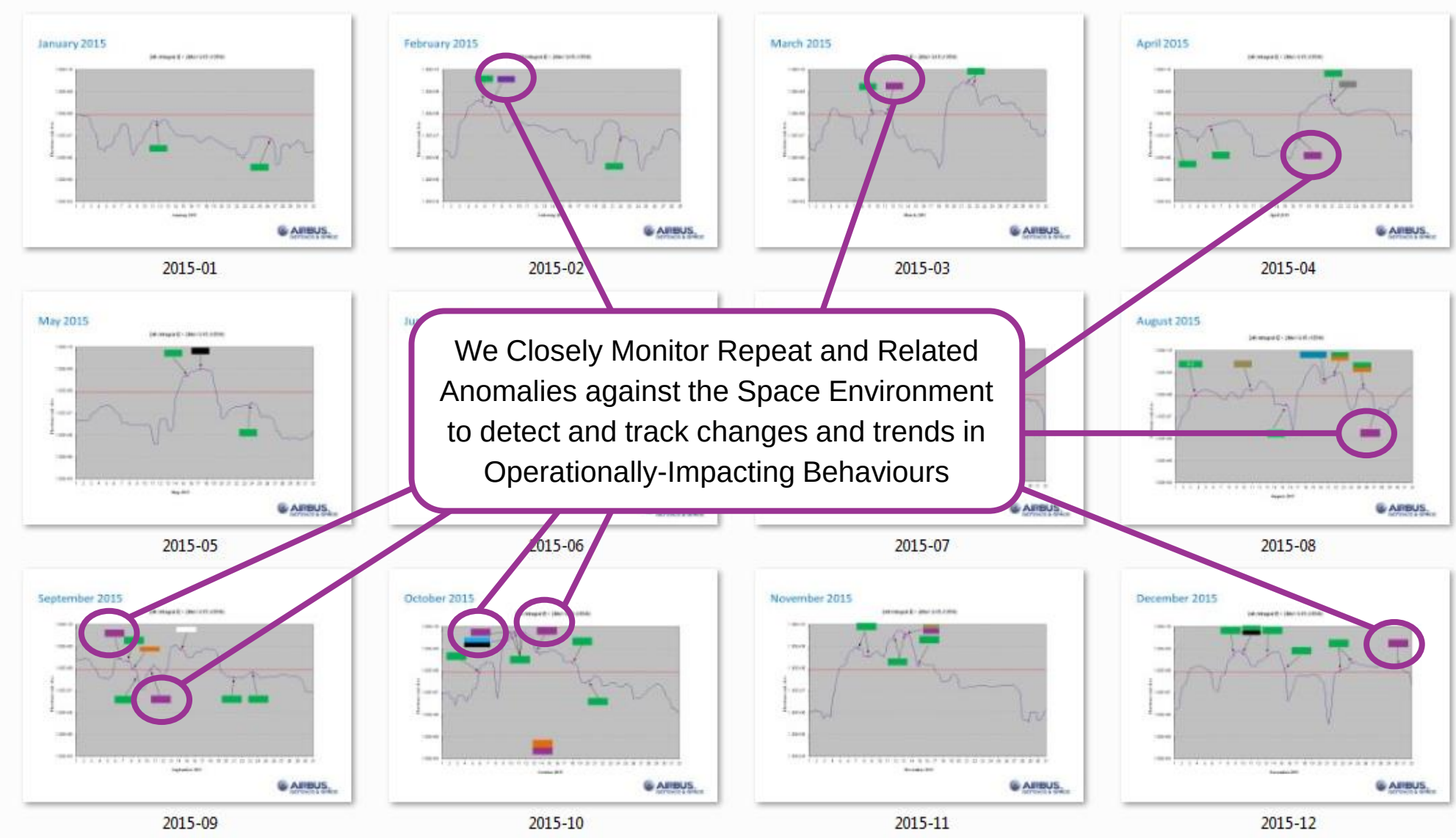


Forecaster commentary: The apparent lag between forecast and actual fluence levels mirrors the lag seen on solar wind persistence models. The sharp drop around the 4th April was due to a CME arriving (which would not be accounted for through persistence).

January 2015



2015 – Deep-Dielectric Discharge Associated Anomalies



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Achieving Operational Management of Severe SpaceWx Events

SpaceWx impacts Operational capability very broadly through many mechanisms and interactions.

- Recognition of the Physical Effects on Space and Ground components,
- Appreciation of the timescales for:
  - Forecasting
  - Our Operational decision-making and Response
  - Our Service Users Reactivity and Requirements

A realistic idea of what SpaceWx mitigations had the potential to be effective has been incrementally realised in table-tops and three real-time, in working environment exercises.

SpaceWx mitigation was demonstrated both possible and of value.

Our development of understanding led that of our Principal Customer, who has become increasingly supportive in the communications elements of the exercises.

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MOSWOC HOLI-STATES

In addition to User-Group 'Broadcast and Published' forecasts, MOSWOC release real-time advice specific to SKYNET when needed in the form of declared Heliographic Observation of Likely Impact (HOLI) States:

A **HOLI-BLUE** would precede a **HOLI-PURPLE**, this being followed by a **HOLI-RED**:

- **HOLI-BLUE** when a Solar Feature *has potential* to cause Severe Space Weather.
- **HOLI-PURPLE** when a Solar Feature *is expected* to be a source of Severe Space Weather.
- **HOLI-RED** when a Solar Feature *has produced* Severe Space Weather which demands mitigative action.

Though likely that there will be some indication of an increasing SpaceWx risk to Operations from the daily MOSWOC forecasts before a **HOLI-BLUE** is issued, this may not be presumed.

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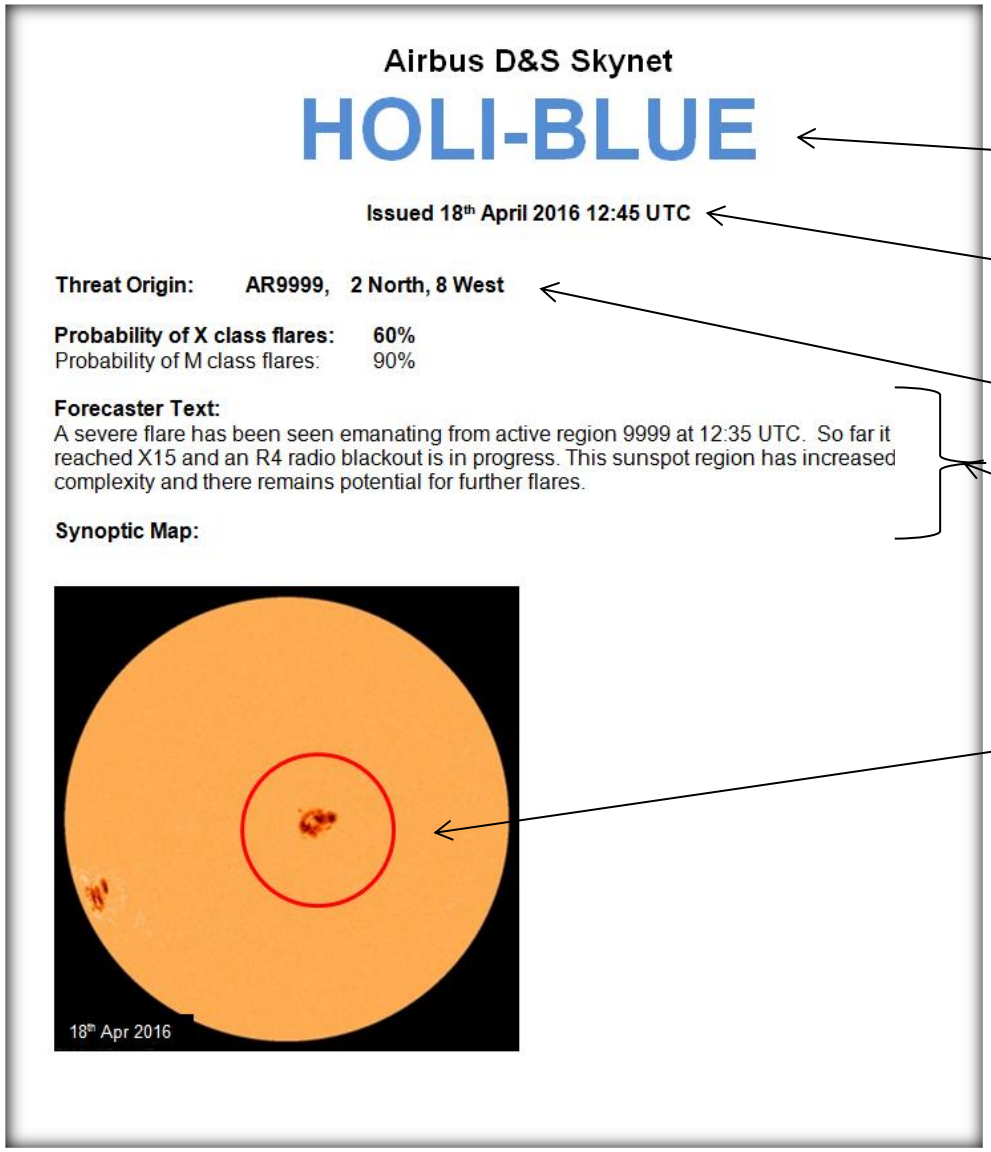
MOSWOC HOLI-STATE Example



Airbus D&S Skynet

HOLI-BLUE

Issued 18th April 2016 12:45 UTC

Threat Origin: **AR9999, 2 North, 8 West**

Probability of X class flares: **60%**
Probability of M class flares: 90%

Forecaster Text:
A severe flare has been seen emanating from active region 9999 at 12:35 UTC. So far it reached X15 and an R4 radio blackout is in progress. This sunspot region has increased complexity and there remains potential for further flares.

Synoptic Map:

18th Apr 2016

State

Issue Date

Threat source summary

Recent history and Trend

Highlighted map

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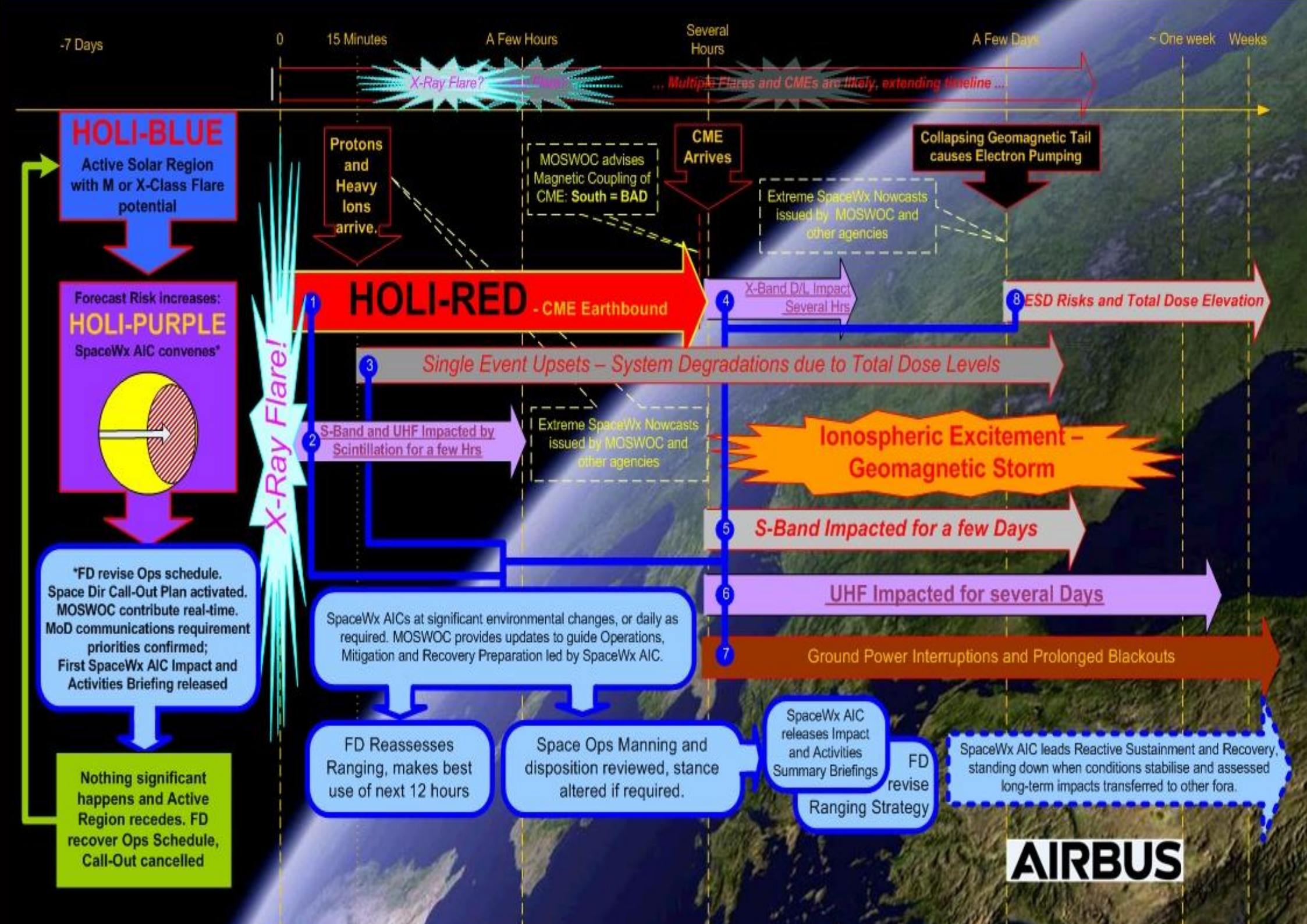
-7 Days
0
15 Minutes
A Few Hours
Several Hours
A Few Days
~ One week
Weeks
X-Ray Flare?
... Multiple Flares and CMEs are likely, extending timeline ...
HOLI-BLUE
Active Solar Region with M or X-Class Flare potential
Forecast Risk increases:
HOLI-PURPLE
SpaceWx AIC convenes*
*FD revise Ops schedule. Space Dir Call-Out Plan activated. MOSWOC contribute real-time. MoD communications requirement priorities confirmed; First SpaceWx AIC Impact and Activities Briefing released
Nothing significant happens and Active Region recedes. FD recover Ops Schedule, Call-Out cancelled
Protons and Heavy Ions arrive.
MOSWOC advises Magnetic Coupling of CME: South = BAD
CME Arrives
Collapsing Geomagnetic Tail causes Electron Pumping
Extreme SpaceWx Nowcasts issued by MOSWOC and other agencies
X-Ray Flare!
1 HOLI-RED - CME Earthbound
4 X-Band D/L Impact Several Hrs
8 ESD Risks and Total Dose Elevation
3 Single Event Upsets – System Degradations due to Total Dose Levels
2 S-Band and UHF Impacted by Scintillation for a few Hrs
Extreme SpaceWx Nowcasts issued by MOSWOC and other agencies
Ionospheric Excitement – Geomagnetic Storm
5 S-Band Impacted for a few Days
6 UHF Impacted for several Days
7 Ground Power Interruptions and Prolonged Blackouts
SpaceWx AICs at significant environmental changes, or daily as required. MOSWOC provides updates to guide Operations, Mitigation and Recovery Preparation led by SpaceWx AIC.
FD Reassesses Ranging, makes best use of next 12 hours
Space Ops Manning and disposition reviewed, stance altered if required.
SpaceWx AIC releases Impact and Activities Summary Briefings
FD revise Ranging Strategy
SpaceWx AIC leads Reactive Sustainment and Recovery, standing down when conditions stabilise and assessed long-term impacts transferred to other fora.
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Training Development Capability

We routinely engage in internal Continuation Training, Assurance Performance Demonstrations and Exercises with our Principal Customer:

- Our attitude to training is positive.
- We retain skills in Training Development and Performance Assessment in-department. This seems to have been a significant advantage.

Our Principal Customer also recognises that the capacity to mitigate Severe SpaceWx needs to become 'normalised' as a recognised part of the Operations Environment:

- Introduction of SpaceWx reporting into 'normal business' was supported in two Principal Customer Exercises.
- Training Exercises were successfully used in identifying internal needs of the Principal Customer and in support of parallel Allied Nation development.
- We work in partnership with the MOSWOC in devising and populating scenarios with Exercise Events.

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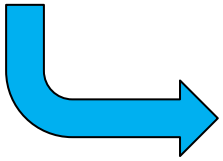
To Train for SpaceWx Mitigation 1/2

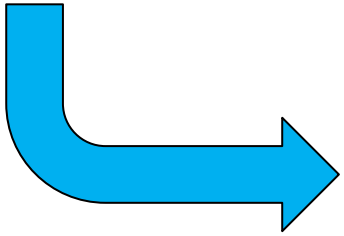
– Suggested Roadmap

1. Create or Obtain a credible Severe SpaceWx challenge timeline. In a Small Group comprising Forecaster and Ops develop an outline Learning Exercise.



Pre-identify gaps and absences in current response capability
Learning Exercise – not a 'Performance Demonstration'.

2. Table-Top the Learning Exercise with a Larger Ops Group, Forecaster and Customer Representatives.



Characterise performance gaps.
Capture ideas, concerns and insights.
Develop and issue for comments a SpaceWx Mitigation Plan in Draft.
Develop and Deliver SpaceWx Training based on these findings.

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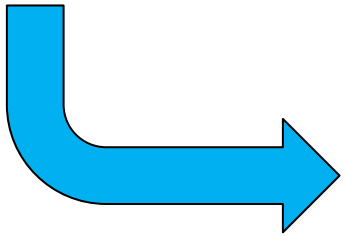
To Train for SpaceWx Mitigation 2/2

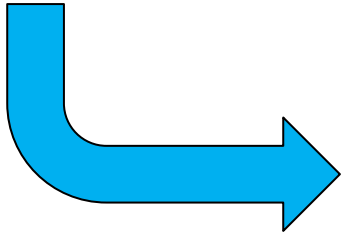
– Suggested Roadmap

3. With the Forecaster, refine the Severe SpaceWx challenge timeline. Create materials for a real-time run in the Live Environment. Use Draft SpaceWx Mitigation Plan. Collect debrief comments.



Identify Operational Optimisations.
Review and correct notification material content and distribution.
Correct Draft SpaceWx Mitigation Plan and make Initial Issue.

4. Develop a follow-on Severe SpaceWx exercise with Forecaster and Customer Representatives. Run in Live Environment.



Refine communications and notification material.
Capture ideas, concerns and insights.
Update SpaceWx Mitigation Plan.
Develop and apply Continuation Training.
Introduce SpaceWx Events into ‘normal’ Assurance Demonstrations and Future Exercises.

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SpaceWx Planning and Mitigation – a Critical Shopping List

- SpaceWx Forecaster Relationship
- Engineering and Operational Systems Understanding
- Customer Requirements, Expectations and Involvement
- Training Development Capability

Future Effort Direction - SpaceWx Understanding for Operations and Service Support

Integration of ‘Routine’ SpaceWx Forecasting to obtain:

For Us:

- Information of Engineering value in Spacecraft On-Orbit Management and Design.
- Operational Planning Optimisation – doing the right things at the best times.
- Increased efficiency in Engineering problem resolution through discrimination of SpaceWx-induced and other faults.

For our Service Users:

- Increases in Service quality and reliability.
- Operational Planning Optimisation – doing the right things at the best times.
- Enhanced capacity for realistic simulation and exercise.

We look forward to working with the MOSWOC on future product definition and delivery.

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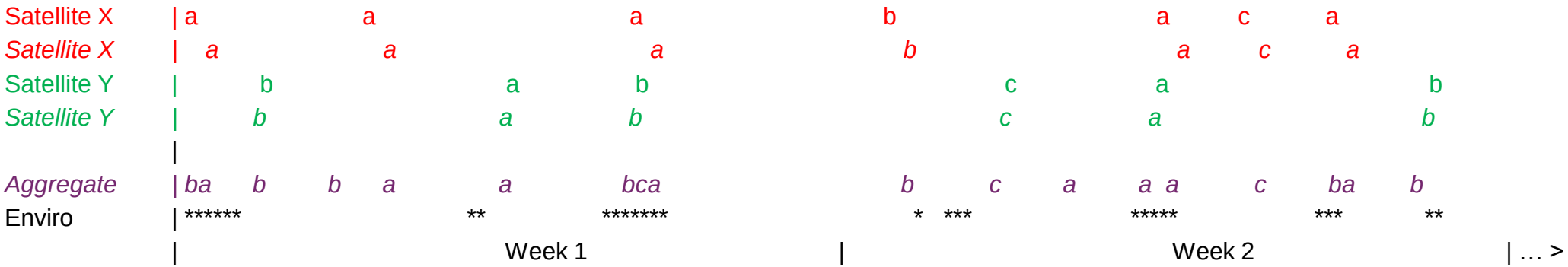
Spacecraft Anomaly Obfuscation – A Proposal



Colours indicate different Operators

Letters indicate Anomalies of generically defined class, common across Satellites and Operators

Italicised indicate that, per spacecraft, and unique to each:

- a shift (+- ~ 20 mins) has been applied along with
- an uncorrelated Orbital Location shift (+- ~ 10 Deg)

These shifts being known only between individual forecaster personnel under NDA with the supported Operator.

Enviro correlation with Aggregate is not adversely affected by the small shifts.

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Point of Contact for Questions

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